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A Game Theoretical Incentive Scheme for Relay Selection Services in Mobile Social Networks

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Abstract —Rapid developments in mobile services and wireless technologies have promoted users to form mobile social networks (MSNs), where bundles can be delivered via opportunistic peer to peer links in a store-carry-forward mode. This mode needs all nodes to work in a cooperative way. However, mobile nodes may be selfish and would not be willing to forward data to others due to the limited resources (e.g., buffer, energy etc.), resulting in a degraded system performance. To tackle the above problem, this paper proposes a novel incentive scheme to stimulate selfish nodes to participate in bundle delivery in MSNs. At first, a virtual currency is introduced to pay for the relay service. Then, a bundle carrier selects a relay node from its friends or other strangers based on its status. Next, a bargain game is employed to model the transaction pricing for relay service. In addition, the simulation results show that the proposal can improve the performance of the existing schemes significantly[1].

Keywords —Mobile social networks, ubiquitous service, bundle delivery, relay selection.

I. INTRODUCTION

Mobile social networks (MSNs) have emerged [1]-[4], where mobile users can create and share their content with each other, by using mobile devices equipped with short range wireless interfaces via peer to peer opportunistic links [5]-[8]. In MSNs, the transmission path between the source and destination is unstable or even unavailable sometimes [9]. Moreover, as the MSNs have unique features with different types of social ties among mobile nodes, e.g., friends, relatives, etc, the transmission path is even harder to setup than the conventional networks without social ties. Therefore, a store-carry-forward fashion is used to deliver bundles to the destination in MSNs. And this delivery fashion needs mobile nodes to work in a cooperative way.

However, in the real life, most of devices are controlled and operated by rational entities which may be selfish sometimes.

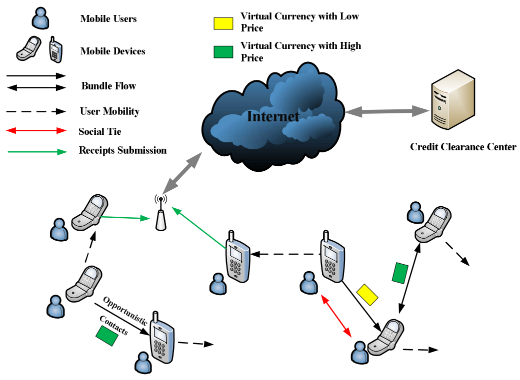

Fig. 1. Schematic diagram of an incentive scheme in the MSN.

In MSNs, a node may not be willing to forward bundles for others due to its limited resources including buffer, energy and so on, which brings down the performance of network. Therefore, to support bundle delivery in MSNs, as shown in Fig.1, an effective incentive scheme should be designed to stimulate selfish nodes to behave cooperatively.

Although many studies have been carried out in designing incentive schemes for wireless networks [10]-[12], most of incentive schemes assume that the transmission path between the source and destination always exists and is stable, where these studies could not be directly applied to MSNs. In addition, the social ties among mobile nodes bring new challenges to study bundle delivery in MSNs. Therefore, it is still a new and open problem to design social-aware incentive schemes for bundle delivery in MSNs.

In this paper, a novel incentive scheme for delivering bundles in MSNs is proposed. Firstly, each node has its own virtual currency and can earn currency as a relay for other nodes. When a node refuses to forward the bundle of others, it will not get paid. Therefore, this node will lose a chance to earn currency to afford the relay service from other nodes in the future, with the result that the proposal can efficiently inhibit nodes from being selfish. Next, a bundle carrier selects relay nodes based on its current status of limited resources. Specifically, if the status of the carrier is loose, it will select one of its friends to be a relay with a low agreement price. Otherwise, if the status of the carrier is tense, it will select any node it encounters even a non friend-node with a high agreement price. Then, a bargain game is employed to model the transaction pricing between the bundle carrier and the relay node, which leads to a subgame perfect Nash equilibrium as the agreement of two players to maximize their benefits. In addition, with simulation experiments, it proves

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that the proposal is efficient to improve both delivery ratio and delay.

The main contributions of the paper are as follows.

- We introduce a novel virtual currency to pay for the relay service, where each node has a certain currency and can earn the currency as a relay for other nodes.
- We propose an approach for the bundle carrier to select the relay node from its friends or other strangers to forward bundles based on the status, which is defined as loose status or tense status.
- We develop a model for the transaction pricing between the bundle carrier and the relay node, where a subgame Nash perfect equilibrium can be used to calculate the agreement price.

This reminder of paper is organized as follows. In Section II, related work is reviewed. Section III presents system model. Section IV introduces the incentive scheme. Performance simulations are shown in Section V. Finally, we give the conclusion in Section VI.

II. Related Work

A. Incentive Schemes

A number of incentive schemes have been proposed to improve the performances of wireless networks. Wang *et al* [11] proposed a data sharing scheme by exploiting local historical paths and users' interest information. It can allow nodes to cooperatively deliver information of interest to one another via the chosen paths by utilizing few transmissions in delay tolerant networks. Chen *et al* [12] proposed a coalitional game theory based incentive scheme to stimulate message forwarding in vehicular ad hoc networks. Wu *et al* [13] used the game theoretic approach to design a novel incentive scheme for stimulating selfish nodes in opportunistic networks where the end-to-end paths are unstable. Wei *et al* [14] introduced a user-centric reputation based incentive protocol for delay tolerant networks, where the game theoretic framework is employed to design costs and rewarding parameter in bundle forwarding. Mahmoud *et al* [15] proposed an incentive system with a payment model in multihop wireless networks, by considering the difference between Web-based applications and cooperation simulation. Ning *et al* [16] proposed a credit-based incentive scheme to stimulate nodes, where the nodal communication is formulated as a two persons' cooperative game by using the Nash Theorem.

Gueguen *et al* [29] presented an incentive scheduling algorithm where the coverage extension is introduced to motive and reward nodes' cooperation. Im *et al* [30] designed an incentive protocol to support content sharing among users in the 3G/WLAN dual mode networks, which can also encourage the content provider to offer a discounted price for downloading high quality content. Lee *et al* [31] proposed a secure incentive protocol to stimulate cooperative diffusion to advertise content over vehicular networks. Tseng *et al* [32] designed a reed-solomon code based incentive scheme to enhance security for vehicular content delivery.

B. Mobile Social Networks

Mobile social applications have attracted more and more attentions. Liang *et al* [17] proposed a three-step data forwarding scheme to enable efficient user cooperation and keep privacy preservation in MSNs, by introducing a new concept of social morality as a fundamental social feature of human society. Wang *et al* [18] proposed a cloud-based multicast scheme with feedback mechanism in MSNs, which has two phases: pre-cloud and inside-cloud. Niyato *et al* [19] presented a controlled coalitional game model for interaction between content providers and the network operator to distribute content. Bulut *et al* [20] presented a friendship-based routing scheme for MSNs, which introduces a novel metric to accurately detect the quality of friendship and make the forwarding decisions. Wu *et al* [21] employed the internal social features of each node for routing, which has two unique processes including social feature extraction and multi-path routing.

Lee *et al* [33] proposed a protocol for reliable D2D communications, where both the spatial user distribution and communication distance distribution are considered. Zhang *et al* [34] introduced a transient connected components aware data forwarding strategies in MSNs, to increase the contact opportunistic to enhance the performance of data forwarding. Hu *et al* [35] presented a distributed multi-age cooperative social protocol to disseminate content, where a content owner can multicast content to his social friends. Lin *et al* [36] introduced a data forwarding scheduling model and a back induction algorithm for promoting nodes to forward message to appropriate relay nodes.

Different from the above works, this paper is to propose a novel incentive driven bundle delivery based on relay selection in MSNs. The work is aimed to stimulate selfish nodes to participate in data forwarding in order to improve the system performance including both delivery ratio and delivery delay.

III. System Model

This section gives an introduction to the network model, node model, and bundle model. The goal of design is also indicated.

A. Network Model

A general MSN is considered where end-to-end connections do not always exist and the routing is made in an opportunistic way. In the MSN, a source node *Src* sends bundles to a destination node *Dst* depending on relays of intermediate nodes $\{N_1, N_2, \cdots N_n\}$.

To enable nodes to pay, there is a Credit Clearance Center (CCC), which is employed to manage the virtual currency for each node [15] [22]. Therefore, before joining the system, every node can register itself to the CCC and obtain its account. Each node should hold a digitally signed receipt for each transaction of relay service and submit the receipt to the CCC. The CCC is a server connected to the Internet, so the node in the MSN can access the CCC when it connects to the Internet. When the destination receives a bundle and submits ACK to the CCC, the node can get paid after the CCC verifying the receipt. Virtual currency can be used in bundle forwarding to pay for bundle relay service, provided by other nodes. If a node does not participate in bundle delivery, it will not get the virtual currency. It means that it will not be able to afford the services from other nodes for its own bundles in the future.

According to the number of message copies in routing, the routing mechanisms can be divided into single-copy and multiple-copy routing. The single-copy means that there is only one node having the message copy in the network anytime. The multiple-copy is that the message is duplicated to generate multiple copies and each copy makes routing decisions independently to reduce transmission delay. However, multiple-copy routing often consumes and occupies a large amount of network resources. Therefore, the single-copy mechanism is adopted to study the incentive scheme in this paper.

In this paper, we focus on the cooperation problem and the incentive scheme to stimulate selfish nodes to participate in data forwarding. Based on the related work [15][38][39], the mechanism of CCC has already been used by a lot of works where the overheads for connection and access to CCC through IP could be controlled and reduced. The reason is that mobile nodes connect to CCC intermittently and only transfer control message (receipt, registration) to reduce both the load and overhead, which needs not so much power of each node. In addition, in this paper as the single copy mechanism is adopted, it need not consume too much energy of the network. There is only one node having message and it needs few of connections.

B. Node Model

The nodes in MSNs are electronic devices that have limited resources, such as buffer, energy, etc. Mobile nodes would exhibit selfishness to save their own resources. The node model is summarized as follows:

1) There are two categories of nodes in networks: cooperative nodes and selfish nodes. Since nodes get payment until the destination receiving the bundle, selfish nodes can't obtain any benefit if they drop bundles.
2) Without incentive strategies, if a node is selfish, it can't accept any bundles from other nodes unless it is the destination of the bundles.
3) Selfish nodes are limited rational. That is to say, with the incentive strategies, these nodes pursue maximum benefit if nodes have sufficient resources. Meanwhile, nodes only consider whether it is beneficial to accept bundles at this moment and don't consider whether they may break the pale when they want to buy other nodes' relay services.

C. Bundle Model

When a source node Src sends a message M to a destination Dst , Src first sets the message head with necessary information and then generates a bundle which is shown in Fig. 2.

ID	*Src*	*Dst*	*TS*	*TTL*	*M*

Fig. 2. Formation of the bundle

Specifically, the bundle is comprised of six components: its bundle sequence number ID, source Src, destination Dst, creating time stamp TS, time-to-live TTL, and message M .

D. Design Goals

Our design goals have two desirable objectives as follows: On one hand, our scheme should be effective in stimulating selfish nodes to participate in bundle delivery in MSNs. On the other hand, it should be efficient without introducing too much extra transmission delay.

IV. The Incentive Scheme

This section proposes an incentive driven bundle delivery scheme based on the relay selection. It aims to provide efficient message dissemination in MSNs when selfish nodes exist. Firstly, it introduces an overview of node status and then provides the detailed node selection strategy. Next, the interaction between bundle carrier and relay node is formulized by employing a bargain game. Finally, the detailed bundle forwarding process between both sides is introduced.

A. Node Status

By considering the factors which can affect the will of a node to participate in bundle delivery in MSNs, a metric of node status is elaborated, including node's buffer, node energy and TTL of the bundle.

1) Buffer: Each node has its limited buffer and the free space of the buffer is gradually decreased with storing more and more data. For simplicity, symbol Bu_i is defined as the percentage of remaining buffer to represent the status of the node on the buffer by

$$Bu_i = \frac{Bu_{re_i}}{Bu_{\max_i}} \times 100\% , \tag{1}$$

where Bu_{re_i} is the remaining buffer of node i currently and $Bu_{\max_i}$ is the maximum buffer of node i .

2) Energy: Similar to the buffer, the energy of each node is also limited. Let E_i denote the percentage of remaining energy as follows.

$$E_i = \frac{E_{re_i}}{E_{\max_i}} \times 100\% , \tag{2}$$

where E_{re_i} is the remaining energy of node i at present and $E_{\max_i}$ is the maximum energy of node i .

3) TTL: Time-To-live (TTL) of a bundle has a significant

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impact on bundle delivery. If the TTL of a certain bundle is going to expire, each node should forward bundle as soon as possible. Otherwise, relay nodes can't get payment. Node status on TTL of the bundle ID_m is defined as

$$T_{ID_m}^{i} = \frac{TTL-(T_c - TS)}{TTL} \times 100\% = \frac{TTL_{re_i}}{TTL} \times 100\%, \quad (3)$$

where $T_{ID_m}^{i}$ is the percentage of remaining TTL of bundle ID_m carried by node i at current time. TTL_{re_i} denotes the remaining TTL of the bundle. TS means the creating time stamp of the bundle and T_c is the current time.

Obviously, at any moment, the above three factors have different impacts on bundle forwarding of each node. Here, a status metric is introduced by

$$SM_{ID_m}^{i} = \alpha \cdot \log_2(1+Bu_i) + \beta \cdot \log_2(1+E_i) + \gamma \cdot \log_2(1+T_{ID_m}^{i}), \quad (4)$$

where $SM_{ID_m}^{i}$ is the status metric of node i on bundle ID_m . α, β and γ are the weight parameters to adjust the importance of buffer, energy and *TTL*, respectively and $\alpha + \beta + \gamma = 1$.

B. Node Selection

For a bundle carrier, it may always wish that there is a low price to buy a relay node's service. As there are many social ties among nodes, a node is usually willing to help its friends even it can only get a low benefit. Therefore, bundle owners always wait for friend-nodes to forward bundle. But, when the remaining buffer, energy of a carrier or the remaining TTL of the bundle is little, the gain will be outweighed by the loss for the carrier if it still keeps waiting for its friend-nodes. Therefore, bundle owners may select their relay nodes according to their current statuses.

A selection threshold σ_i is denoted for node i to decide whether it is appropriate to wait for friends. When node i encounters a relay candidate, it will check its current status. If $SM_{ID_m}^{i} \geq \sigma_i$ which denotes the status of node i is loose, it tends to purchase relay service from its friend-nodes, where the agreement price is usually low. If $SM_{ID_m}^{i} < \sigma_i$ which denotes the status of node i is tense, it will forward bundle to relay candidate regardless of whether the candidate is a friend or not.

Actually, when the status is loose, it is unreasonable that a carrier waits its friend-nodes for a long time, as it has few friends or it takes long time to encounter a friend. Therefore, a number $L_{ID_m}^{i}$ denotes how many candidates node i encounters at most for bundle ID_m when the status is loose.

$$L_{ID_m}^{i} = \left\lfloor k_i SM_{ID_m}^{i} \right\rfloor, \quad for\ SM_{ID_m}^{i} > \sigma_i, \quad (5)$$

Here, $\lfloor \bullet \rfloor$ represents the floor function, k_i reflects the change of status including the attenuation of energy and buffer.

C. Bargain Game

When a bundle carrier encounters a relay node, the carrier may want to buy the relay node's service, where the bundle carrier is seen as a buyer and the relay node is looked upon as a seller. Both the buyer and seller usually want to pursue their largest benefits. That is to say, the buyer hopes that the price of the relay service is low, whereas the seller wants the price to be as high as possible. Therefore, a bargaining game is employed to formulate a pricing model, in presence of the conflict of interest between buyers and sellers.

These two players of the bargain game are defined by $N = \{B, S\}$, to present the nodes that are buyer and seller of a relay service, respectively. The reserve price of bundle ID_m of a buyer B is denoted by $RP_{ID_m}^{B}$, to represent the bearable maximum buying price of a relay service for bundle ID_m. Then it can be obtained by

$$RP_{ID_m}^{B} = \rho_B \times si_{ID_m} \times \frac{VC_B}{SM_{ID_m}^{B}}, \quad (6)$$

where ρ_B is the reserve factor of the buyer and si_{ID_m} is the size of the bundle ID_m. VC_B denotes the virtual currency that the buyer has currently. From (6), it can be known that the reserve price of the buyer is higher when the bundle has a larger size or the buyer has more virtual currency. And the tenser the status of buyer B is, the higher the reserve price becomes.

Similarly, the reserve price of seller S can be denoted by $RP_{ID_m}^{S}$ to represent the bearable minimum selling price of its relay service for bundle ID_m. And it can be obtained by

$$RP_{ID_m}^{S} = \rho_S \times si_{ID_m} \times \frac{VC_S}{\varepsilon Bu_S + \omega E_S} \times \frac{1}{e^{\eta_{BS}}}, \quad (7)$$

where e is the Euler's number, and ρ_S is the reserve factor of the seller. Here, VC_S denotes the virtual currency that the seller has. Bu_S means the percentage of remaining buffer of the seller and E_S denotes percentage of the remaining energy of the seller. ε and ω are the weight parameters satisfying $\varepsilon + w = 1$. And η_{BS} is the friendship factor between buyer B and seller S, which can be shown by

$$\eta_{BS} = \begin{cases} 1 & if\ \ buyer\ and\ seller\ are\ friends \\ 0 & otherwise \end{cases}. \quad (8)$$

Based on (7), if the resource of the seller is not enough, it

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will have a low will to relay bundle (the price is high). If the buyer has not enough virtual currency, it will have a high will to relay bundle (the price is low). In addition, a friendship factor is introduced to consider the negotiation between two friends or two strangers. That is to say, if the buyer and the seller are friends, the presence price will be low, otherwise the presence price should be high.

The classical Rubinstein-Stahl bargain game is introduced as a solution to model the interaction between two players who make a bargain to divide a "cake" of size π [23]. They negotiate with each other by proposing offers alternately. In this paper, the bargain game is employed for modeling the division of the difference value C for the reserve prices of buyer B and seller S, where the difference value C is the "cake".

$$C = RP^{B}_{ID_m} - RP^{S}_{ID_m} . \tag{9}$$

As the players in MSNs may be greedy and selfish, they try to get as much proportion of the "cake" as possible in the bargain game. Their utility functions are denoted as

$$u_S(x_s) = x_S C - R_s , \tag{10}$$
$$u_B(x_B) = x_B C - T_B , \tag{11}$$

where $u_S(\cdot)$ and $u_B(\cdot)$ are the utility functions of the seller and the buyer. T_B and R_S denote the costs associated with the transmission and reception of bundle. x_S and x_B mean the proportion of the "cake" divided for the seller and buyer respectively. We have

$$X = \{(x_S, x_B) \in R^2 : x_S + x_B = 1, x_S \ge 0, x_B \ge 0\} . \tag{12}$$

Here the pair (x_S, x_B) is the offered division by the seller or the buyer.

The bargain procedure between a buyer and a seller is as follows. In round 1, the seller is at first to make an offer $x_1 = (x_{S1}, x_{B1})$, where $x_1 \in X$. x_{S1} and x_{B1} represent the proportion of the "cake" that seller and buyer want. According to this offer, the buyer can either accept or reject the offer. If the buyer accepts, the agreement is reached and the bargain game is over. Otherwise, the bargain game comes to round 2, and the buyer is turned to make a new offer $x_2 = (x_{S2}, x_{B2})$, where $x_2 \in X$. x_{S2} and x_{B2} are the proportion of the "cake" which the seller and buyer are interested in, respectively. Then, the seller must either accept or reject the new offer that the buyer provides. Similarly, if the seller accepts, the game is over. Otherwise, the game comes to the next round. Therefore, this bargain game is an infinitely repeated game.

Obviously, it takes some cost and time to carry out each round of the negotiation in bargain game. Therefore, there should be a final agreement accepted by both sides as soon as possible in the negotiation. In other words, each player in the game has its own patience, which is also called the discount factor. This discount factor can depict the utilities of both the buyer and seller which are decreased over the time. We denote δ_S and δ_B as the patience factors of the seller and the buyer respectively. Therefore, if the patience factors are considered in the game, the utility functions should be as follows.

$$u^r_S(x_s) = {\delta_S}^{r-1}(x_S C - R_s) , \tag{13}$$
$$u^r_B(x_B) = {\delta_B}^{r-1}(x_B C - T_B) , \tag{14}$$

where $u^r_S(\cdot)$ and $u^r_S(\cdot)$ are the utility functions of the seller and buyer in round r .

In the bargain game, the patience factor can affect the results of negotiation for both sides. The following presents how to determine the patience factor for the seller and buyer respectively. If its status is tenser, buyer B will have lower patience. Moreover, the patience factor is varied from zero to one. Therefore, the conditions for patience functions of the buyer B can be defined as follows,

$$\frac{d\delta_B(VC_S \cdot SM^{B}_{ID_m})}{d(VC_S \cdot SM^{B}_{ID_m})} > 0, \quad \delta_B(0) = 0, \ \delta_B(\infty) = 1 , \tag{15}$$

where $SM^{B}_{ID_m}$ is the status metric of buyer B on bundle ID_m . The function for the patience of buyer B [24] is defined by

$$\delta_B(t) = \frac{e^{vt} - e^{-vt}}{e^{vt} + e^{-vt}} , \tag{16}$$

where v is the patience coefficient of the buyer.

For seller S, due to the limited buffer and energy, it may behave selfishly to pursues maximum benefit. Therefore, if the status of the seller is looser, it will have lower patience for relay service of a bundle, because it wants to relay more bundles from different nodes to earn more money. If the status of the seller is tenser, it will have higher patience, because it wants to obtain money from the buyer as much as possible. Moreover, the patience factor is from zero to one. Therefore, the conditions for patience function of seller S are defined as follows.

$$\frac{d\delta_S(VC_S \cdot (\varepsilon Bu_S + \omega E_S))}{d(VC_S \cdot (\varepsilon Bu_S + \omega E_S))} < 0, \quad \delta_S(0) = 1, \ \delta_S(\infty) = 0 . \tag{17}$$

Similarly, the following can be used to express the patience function [24] for seller S .

$$\delta_S(t) = 1 - \frac{e^{\mu t} - e^{-\mu t}}{e^{\mu t} + e^{-\mu t}} , \tag{18}$$

where μ is the patience coefficient of the seller.

According to the above description, in order to avoid the loss on negotiation, each player prefers reaching agreements as soon as possible. Then, we have the following theorems.

Theorem 1: In the proposed bargain game, there exists a unique subgame perfect Nash equilibrium. According to Nash equilibrium, the bargain ends in one round with the following agreement.

$$x_S^* = \frac{C - \delta_B C - \delta_B \delta_S R_S + \delta_B R_S + \delta_B T_B - T_B}{C - \delta_B \delta_S C} \tag{19}$$

$$x_B^* = \frac{\delta_B C - \delta_B \delta_S C + \delta_B \delta_S R_S - \delta_B R_S - \delta_B T_B + T_B}{C - \delta_B \delta_S C}. \tag{20}$$

Proof: A subgame Nash perfect equilibrium is constructed by backwards induction.

Since this bargain game is infinitely repeated, it is hard to find the point which the back induction is started from. Therefore, there should have been a subgame Nash perfect equilibrium in game, where the seller makes an offer x^* and the buyer accepts this offer in round 1. Similarly, if the game begins from round 3, the seller will give the offer x^* and the buyer will accept this offer. Therefore, this infinitely repeated game can be seen as a bargain game with three rounds to analyze and obtain the equilibrium. In the following analysis, the offer x denotes the proportion of the difference value C that seller S can get, where $x_S = x$, $x_B = 1 - x$.

Started from round 3, the last mover should be buyer B . It will accept proposal x^* offered by seller S . Next, move to round 2, where buyer B is turned to give an offer. Seller S accepts the proposal x_2 only when

$$u_S^2 \ge u_S^3$$
$$\delta_S (x_2 C - R_S) \ge \delta_S^2 (x^* C - R_S)$$
$$x_2 \ge \frac{\delta_S x^* C - \delta_S R_S + R_S}{C}.$$

Then, buyer B makes a proposal x_2^* that maximizes its utility.

$$\begin{aligned} & x_2^* \\ &= \arg\max_{x_2} (u_B^2) \\ &= \arg\max_{x_2} \begin{cases} \delta_B [(1 - x_2) C - T_B], if \ x_2 \ge \dfrac{\delta_S x^* C - \delta_S R_S + R_S}{C} \\ u_B^3, \qquad if \ \ x_2 < \dfrac{\delta_S x^* C - \delta_S R_S + R_S}{C} \end{cases} \\ &= \frac{\delta_S x^* C - \delta_S R_S + R_S}{C}. \end{aligned}$$

Next, let's move to round 1 where seller S is turned to give an offer. Buyer B accepts a proposal only when

$$u_B^1 \ge u_B^2$$
$$(1 - x_1) C - T_B \ge \delta_B [(1 - x_2^*) C - T_B]$$
$$x_1 \le \frac{C - \delta_B [(1 - x_2^*) C - T_B] - T_B}{C}$$
$$x_1 \le \frac{C - \delta_B C + \delta_B \delta_S x^* C - \delta_B \delta_S R_S + \delta_B R_S + \delta_B T_B - T_B}{C} = \Delta .$$

Then, Seller S makes a proposal x_1^* that maximizes its utility.

$$\begin{aligned} x_1^* &= \arg\max_{x_1} (u_S^1) \\ &= \arg\max_{x_1} \begin{cases} x_1 C - R_S, \ if \ x_1 \le \Delta \\ u_S^2, \qquad if \ \ x_1 > \Delta \end{cases} \\ &= \frac{C - \delta_B C + \delta_B \delta_S x^* C - \delta_B \delta_S R_S + \delta_B R_S + \delta_B T_B - T_B}{C}. \end{aligned}$$

As the equilibrium of the infinitely repeated bargain game is equal to the equilibrium of the bargain game with three rounds, it can be obtained by,

$$x_1^* = x^*$$
$$\frac{C - \delta_B C + \delta_B \delta_S x^* C - \delta_B \delta_S R_S + \delta_B R_S + \delta_B T_B - T_B}{C} = x^*$$
$$x^* = \frac{C - \delta_B C - \delta_B \delta_S R_S + \delta_B R_S + \delta_B T_B - T_B}{C - \delta_B \delta_S C}.$$

Therefore, the subgame Nash perfect equilibrium becomes

$$x_S^* = \frac{C - \delta_B C - \delta_B \delta_S R_S + \delta_B R_S + \delta_B T_B - T_B}{C - \delta_B \delta_S C}$$
$$x_B^* = \frac{\delta_B C - \delta_B \delta_S C + \delta_B \delta_S R_S - \delta_B R_S - \delta_B T_B + T_B}{C - \delta_B \delta_S C}.$$

This completes our proof.

Theorem 2: The transaction price TP of a relay service for the bundle ID_m is

$$TP = RP_{ID_m}^B - x_B^* C \tag{21}$$

Meanwhile, if the buyer and seller are two friends, the transaction price will be lower than that if they are not friends.

Proof: Firstly, we analyze the scenario that the buyer and seller are friends. With a transaction price TP_f , it can be obtained by,

$$RP_{ID_m}^B - TP_f - T_B = x_B^* C_f - T_B ,$$
$$TP_f = RP_{ID_m}^B - x_B^* C_f .$$

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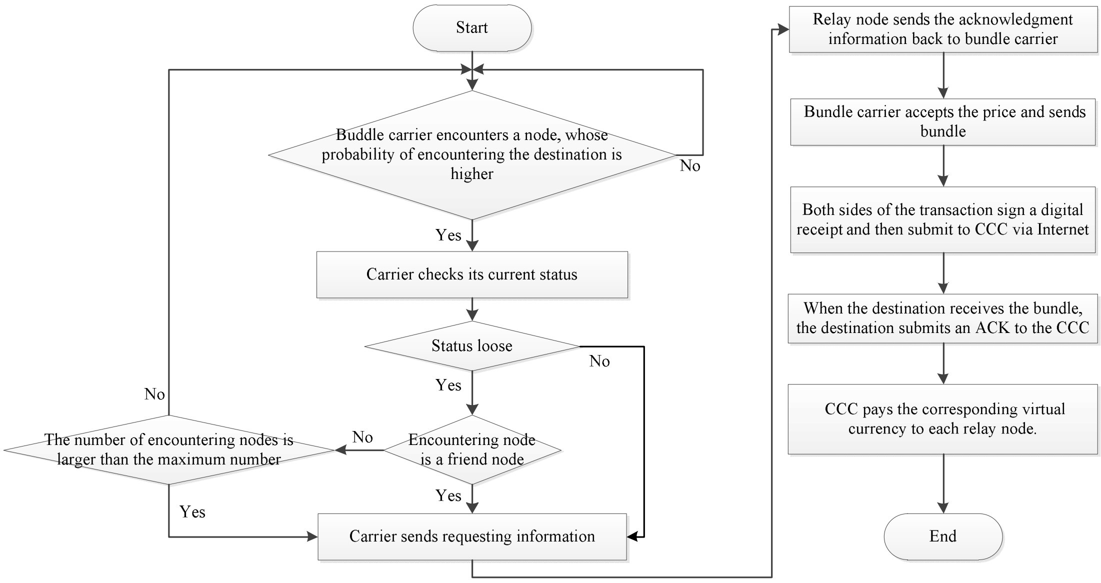

Fig. 3 The flow chart of the proposed scheme

Here, C_f is the difference value of buyer B and seller S who are friends.

According to (6), (7) and (8), the C_f can be calculated as follows.

$$C_f = RP_{ID_m}^B - RP_{ID_m}^S$$
$$= \rho_B \times si_{ID_M} \times \frac{VC_B}{SM_{ID_m}^B} - \rho_S \times si_{ID_M} \times \frac{VC_S}{\varepsilon Bu_S + \omega E_S} \times \frac{1}{e}.$$

Therefore, if the player and the seller are friends, the transaction price TP_f will be

$$TP_f$$
$$= RP_{ID_m}^B - x_B^*(\rho_B \times si_{ID_M} \times \frac{VC_B}{SM_{ID_m}^B} - \rho_S \times si_{ID_M} \times \frac{VC_S}{\varepsilon Bu_S + \omega E_S} \times \frac{1}{e})$$
$$= RP_{ID_m}^B - \frac{\delta_B C_f - \delta_B\delta_S C_f + \delta_B\delta_S R_S - \delta_B R_S - \delta_B T_B + T_B}{1-\delta_B\delta_S}.$$

Then, we analyze the scenario that the buyer and seller are not friends. With a transaction price TP_{nf}, it can be obtained by,

$$RP_{ID_m}^B - TP_{nf} - T_B = x_B^* C_{nf} - T_B,$$
$$TP_{nf} = RP_{ID_m}^B - x_B^* C_{nf},$$

Here, C_{nf} is the difference value of buyer B and seller S who are not friends.

According to (6), (7) and (8), C_{nf} can be calculated as follows.

$$C_{nf} = RP_{ID_m}^B - RP_{ID_m}^S$$
$$= \rho_B \times si_{ID_M} \times \frac{VC_B}{SM_{ID_m}^B} - \rho_S \times si_{ID_M} \times \frac{VC_S}{\varepsilon Bu_S + \omega E_S}.$$

Therefore, if the player and the seller are not friends, the transaction price TP_{nf} becomes

$$TP_{nf}$$
$$= RP_{ID_m}^B - x_B^*(\rho_B \times si_{ID_M} \times \frac{VC_B}{SM_{ID_m}^B} - \rho_S \times si_{ID_M} \times \frac{VC_S}{\varepsilon Bu_S + \omega E_S})$$
$$= RP_{ID_m}^B - \frac{\delta_B C_{nf} - \delta_B\delta_S C_{nf} + \delta_B\delta_S R_S - \delta_B R_S - \delta_B T_B + T_B}{1-\delta_B\delta_S}.$$

Then, the comparison between TP_f and TP_{nf} is carried out by,

$$TP_f - TP_{nf}$$
$$= RP_{ID_m}^B - \frac{\delta_B C_f - \delta_B\delta_S C_f + \delta_B\delta_S R_S - \delta_B R_S - \delta_B T_B + T_B}{1-\delta_B\delta_S}$$
$$- RP_{ID_m}^B + \frac{\delta_B C_{nf} - \delta_B\delta_S C_{nf} + \delta_B\delta_S R_S - \delta_B R_S - \delta_B T_B + T_B}{1-\delta_B\delta_S}$$
$$= \frac{\delta_B(1-\delta_S)(C_{nf} - C_f)}{1-\delta_B\delta_S}$$
$$= \frac{\delta_B(1-\delta_S)}{1-\delta_B\delta_S} \times \rho_S \times si_{ID_M} \times \frac{VC_S}{\varepsilon Bu_S + \omega E_S}(\frac{1}{e} - 1) < 0$$
$$TP_f < TP_{nf}$$

Therefore, if the buyer and seller are friends, the transaction price is lower than that if they are not. This completes our proof.

TABLE 1: PARAMETERS

Parameter	Value
N: the number of users in the network	20
Bu_{max} : the maximum buffer of each node	30MB
E_{max} : the maximum energy of each node	2000w
TTL: the time-to-live value of a bundle	6h
$\{\alpha, \beta, \gamma\}$: the weight parameters in (4)	{0.3, 0.3, 0.4}
σ : the section threshold of each node	0.7
k: the change of status	3
$\{\varepsilon, \omega\}$: the weight parameters in (7)	{0.5, 0.5}
v: the patience coefficient of the buyer	0.6
μ : the patience coefficient of the seller	0.6
$\{T_b, R_s\}$: the costs associated with the transmission and reception of bundle, respectively	{0,0}

D. Bundle Delivery Framework

The flow chart of the proposed incentive scheme is shown in Fig. 3, and the detailed executing process is summarized as follows.

1) When the bundle ID_m carrier encounters a node, whose probability of encountering the destination is higher than that of the carrier, the carrier first checks its current status by (4). If the status is loose, the carrier will check whether the encountering node is its friend-node or not. If this node is a friend-node, the carrier will send the requesting information including bundle ID, the size of the bundle, the reserve price (calculated by (6)), and the patience factor (calculated by (16)). If this node is not a friend-node, the carrier will wait for other friend-node until the number of encountering nodes is equal to the maximum number decided by (5). If the status of carrier is tense, the carrier will immediately send the requesting information.
2) When the relay node receives the requesting information, if the relay node is not the destination, it will calculate its reserve price by (7). If the reserve price of the relay node is lower than that of the bundle carrier, the relay node calculates the transaction price by (7), (8), (18), (20), and (21). Then the relay node will send acknowledgment information back to bundle carrier including bundle ID, the transaction price, the reserve price, and the patience factor of the relay node.
3) The bundle carrier will check whether the utility it has got is positive or not. If $u_B^1 > 0$, the bundle carrier will accept the price and send bundle ID_m to the relay node. Otherwise, it will wait for another node.
4) After the relay node receives the bundle, both sides of the transaction sign a digital receipt which includes the bundle ID and price, and each side holds a copy of this receipt. The receipts will be submitted to the CCC when they connect to the Internet. Then the bundle carrier deletes the bundle ID_m in its buffer.
5) When the destination receives the bundle, the destination submits an ACK to the CCC including the bundle ID when it connects to Internet. Then the CCC pays the corresponding virtual currency to each relay node based on the digital receipts.

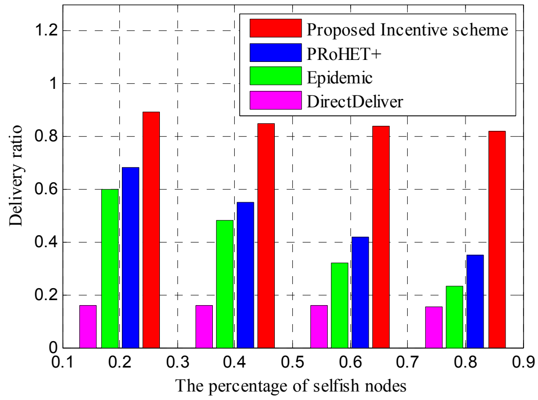

Fig. 4. Delivery ratio vs. percentage of selfish nodes

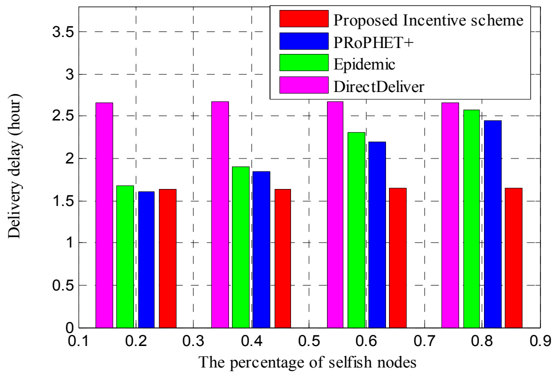

Fig. 5. Delivery delay vs. percentage of selfish nodes

V. PERFORMANCE EVALUATIONS

In this section, the performance of the proposed incentive scheme is evaluated. This section first introduces simulation setup, and then shows the performance comparison and discussions.

A. Simulation Setup

In the simulation, there are 20 MSN nodes with a transmission radius of 50 meters which are uniformly deployed in an area of 1 km × 1 km. Each node moves at a speed uniformly spread in [0.5, 2.5] m/s with the random direction model. Therefore, according to [25], the average contact rate of two nodes is 0.37 contacts per hour to determine the contact time of each pair of nodes for the simulation in Matlab.

The source node generates bundles with uniform time interval of 10 minutes, and the size of each bundle is 2MB. We set the buffer size of each node to be 30MB. The TTL of the bundle is 6 hours. The destination of the bundle is randomly selected from the other nodes except source nodes.

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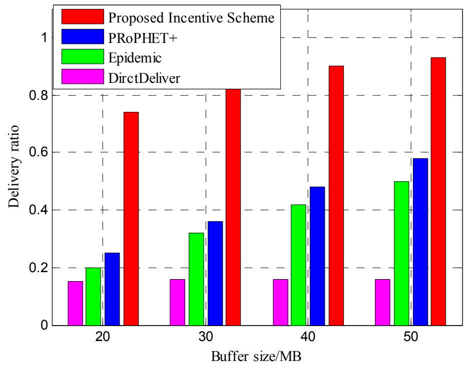

Fig. 6. Delivery ratio vs. buffer size

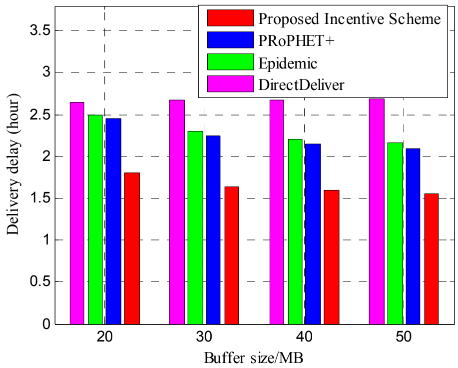

Fig. 7. Delivery delay vs. buffer size

The energy of each node decreases according to $E_{re} = e^{-\lambda t} E_{\max}$ where $\lambda = 0.2$. And the weight parameters are $\alpha = 0.3$, $\beta = 0.3$, $\gamma = 0.4$. Table 1 lists the value of parameter in this simulation.

The social ties among mobile nodes are generated by using BA model [26], which can generate a scale-free social network model. Each simulation runs for 12 hours and is repeated by 10 times. Every node has an initial virtual currency of 100 and pays the corresponding currency for each delivered bundle.

The following metrics are used to compare different delivery schemes:

- **Delivery Ratio**: the proportion of the bundles that have been delivered to the bundles of being created.
- **Delivery Delay**: the average delivery time that is used to deliver bundles from source to destination.

B. *Performance Comparison*

The incentive scheme is compared with three conventional delivery schemes as below.

Epidemic [27]: In this scheme, bundles are flooded when a bundle carrier encounters other nodes that do not possess a copy of the bundle.

Direct Deliver [28]: In this scheme, the source holds the bundle until it comes in contact with the destination.

PRoPHET+ [37]: In this scheme, the carrier forwards the bundle to other node with the weighted function determined by node's buffer size, power, and the predictability.

Fig. 4 shows the delivery ratio by comparing the proposal with other three schemes. From Fig. 4, it can be known that the proposal outperforms other existing delivery schemes when the number of selfish nodes in the MSNs changes. In the epidemic scheme, since there is no incentive strategy, selfish nodes refuse to relay bundles. Therefore, it causes that many bundles are dropped when bundles are expired or the buffer of the node is overflow. In the PRoPHET+, due to the selfish nodes, the bundles can not be delivered to the destination with a high delivery ratio. For the direct delver scheme, it is the worst since it only delivers bundle when arriving at the destination.

Fig. 5 shows the comparison of delivery delay. From this figure, we can know that the proposed incentive scheme has the lowest delay as almost all nodes participate in bundle delivery. In epidemic, because some nodes are still selfish, bundle owners are acquired to wait for cooperative nodes. In PRoPHET+, the carriers have to wait the cooperation nodes for bundle forwarding, resulting in a long delay. For direct deliver, it takes long time to encounter the destination, with a result of the largest delay.

Next, we test the delivery ratio and delivery delay with different buffer size, where the buffer size is changed from 20MB to 50 MB and the percentage of selfish nodes is fixed to be 0.6. In Fig.6, although all the delivery ratios of three schemes increase when the buffer size of each node is increased, the proposal has the maximum delivery ratio. In the epidemic scheme, bundles are stored in the buffer of a node with long time, resulting in that many bundles can not be forwarded when the buffer is overflow. In PRoPHET+, as many bundles may be dropped when the limited buffer of each node is full, the delivery ratio can not be improved much. In the direct delivery scheme, due to the lack of cooperation of nodes, bundles can be forwarded only when the source node encounters the destination node. Therefore, the delivery ratio is the lowest and is almost unchanged with the increase of buffer size. For the proposed incentive scheme, mobile nodes are willing to forward bundles through bargain even though each node has a small-sized buffer.

Fig. 7 shows the delivery delay when the buffer size of each node is changed. From Fig. 7, we can observe that the delivery delay of each scheme decreases with the increase of buffer size. In the epidemic scheme, mobile nodes have to wait for the cooperative nodes to forward bundles. And, due to the small buffer size, some nodes can not receive bundles or drop old bundles when the buffer is full. As a result, it takes long time to forward bundles to the destination node. In the PRoPHET+, due to the limited buffer, the node drops old bundles when the buffer is full, where the delivery delay can not be reduced efficiently. In the direct delivery scheme, the forwarding of a bundle depends on the encounter between the source node and destination node, which takes long time. Compared with the other three schemes, the delivery delay of the proposal is the minimum. In the proposal, although the buffer size is limited, the mobile nodes are willing to forward bundles with an appropriate transaction price, resulting in that the bundle can reach the destination quickly.

Through the above experiments, it can be known that the proposed incentive scheme can achieve the largest delivery ratio and the lowest delivery delay, compared with other existing protocols when the number of selfishness nodes is changed. In addition, when the buffer of each node is changed, our incentive scheme can also obtain better performances in term of both the delivery ratio and delivery delay than others. Due to these results, it can be concluded that our proposal can outperform other existing algorithms.

VI. Conclusion

This paper has presented a game theoretical incentive scheme based on the relay selection, to stimulate selfish nodes to participate in bundle delivery in MSNs. In the proposal, the bundle carrier could select a friend-node or a stranger to be a relay node based on its status and then pay for corresponding virtual currency for relay service. In addition, the transaction pricing can be decided by a bargain game, where a subgame Nash perfect equilibrium is used to calculate the agreement price. Extensive simulations show that the proposal can outperform other existing schemes with a higher delivery ratio and lower delivery delay. The future work will be security issues of payment if there are some fraudulent nodes in the MSNs.

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